FIRS/T166 #166

FAO Fisheries Technical Paper No. 166 FIRS/T166

JUL 26 1977

GOALS AND OBJECTIVES OF FISHERY MANAGEMENT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, March 1977

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M-43
ISBN 92-5-100281-9

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PREPARATION OF THIS REPORT

This paper has been prepared as part of the support of a study initiated by the Advisory Committee on Marine Resources Research (ACMRR), aimed at promoting the better management of fish resources. The present paper takes into account the comments by some members of ACMRR and others on an earlier version. D.L. Alverson (Chairman of ACMRR), W. Wooster, E. Bayagbona, G.D. Waugh, D.H. Cushing and G. Saetersdal were among those who provided comments.

Distribution:

FAO Department of Fisheries
Fishery Officers in FAO Regional Offices
Selector SM
Members of ACMRR

Bibliographic Entry:

Gulland, J.A. (1977)
FAO Fish.Tech.Pap., (166):14 p.
Goals and objectives of fishery management

Fishery management. Fishery resources. Fishing mortality. Yield. Potential yield. Population dynamics. Recruitment.

CONTENTS

		Page
1.	INTRODUCTION	1
2.	GOALS AND OBJECTIVES	1
3.	MEASURES OF INPUT AND OUTPUT	3
4.	LONG-TERM AND SHORT-TERM INTERESTS	4
5.	THE POSSIBILITIES OF DEFINITION	6
6.	FUNCTIONS OF SCIENTIFIC ADVICE	7
7.	MECHANICS OF ADVICE	12
8.	REFERENCES	13

Abstract

This paper discusses the problems of determining what should be the aims and objectives to be pursued when managing fisheries. The concept of maximum sustained yield (MSY) has proved useful in simple situations. A less narrowly defined objective is needed to take account of interactions between different fisheries and fish stocks; of measures of output (economic return, employment, etc.) other than the simple weight harvested; of the inputs (fuel, energy, etc.) involved in taking the catch; and of the need to balance immediate and long-term interests (i.e., between catching more fish now, and having more to catch next year or the year after). It is probably not possible to replace MSY by a single, simply defined objective that satisfies all these conditions. In practice management policies will have to be determined in each case in the light of current objectives of society, and of the scientific understanding of the stocks, bearing in mind that they will never be completely accurate. Some of the problems of providing scientific advice in a way that appropriate management decisions can be taken are discussed. Problems of stock and recruitment, interaction between species, and inherent variability of natural systems are likely to present particular difficulties.

1. INTRODUCTION

Recent events - the discussions at the U.N. Conference on the Law of the Sea, the increased public concern for the natural environment, and the growing pressure on the oceans' living resources - have increased the interest in the practice of fishery management and in the concepts on which this practice has been based. At its Eighth Session (Sesimbra, September 1975), the Advisory Committee on Marine Resources Research (ACMRR) recognized that there was the need "to critically examine the general concepts relative to the goals and objectives of managing living resources, as well as the scientific and technical basis for achieving stated goals".

This paper is intended as background material for carrying out this examination, rather than a conclusive statement on the subject. It has two main purposes - a discussion of the different goals (including an examination of the extent to which it is useful to attempt any strict definition of these goals), and a review of the scientific and technical basis for achieving these goals.

2. GOALS AND OBJECTIVES

The basic concepts of fishery management, as these are now most commonly understood, grew up in the period just before and immediately after the second world war, when the population dynamics of single species fish stocks were beginning to be understood. For these stocks it became accepted, following especially the concepts of the sigmoid population growth curve (Graham, 1939), expressed in clearer algebraic terms in Schaefer's (1954) parabolic curve, that the greatest sustained yield would be taken at some intermediate level of fishing rate and stock size. No explicit consideration was given to the balance between long-term and short-term interests, but it was implied, by examining only the equilibrium situation, that long-term interests were dominant, i.e., that if the stock were "overfished", the amount of fishing should be reduced (hence giving an immediate short-term reduction in catch) in order to achieve a long-term sustained benefit.

This approach, expressed most concisely by the definition of "maximum sustainable yield (MSY)" as the objective of fishery management, is too simple in at least four ways - the size of the system being considered; the measures of input; the measures of output; and the trade-off between long-term and short-term interests.

The simple concepts, including MSY, treated the stock of fish of immediate interest as being in biological isolation, with the only factor disturbing it from its supposedly unique equilibrium unexploited situation being the fishing on that stock. Life is not now so simple. More stocks are being exploited, or are of interest in other ways as is shown, for example, by the public concern to increase the number of marine mammals, or decrease the number of sharks. The management of any one stock must take account of the effects that fishing on that stock may have on other stocks and the fishing on them. These could be in either direction - e.g., increased catches of cod may reduce predation by cod on herring, and hence allow larger catches of herring, but increased catches of herring may reduce the food supply of cod, and hence reduce cod catches. These interactions are in general difficult to quantify and may be surprising. For example, it is possible that one of the more significant interactions between North Sea commercial fish species is the predation by smaller pelagic species (herring and mackerel) on the demersal species (cod, haddock, plaice) when the latter are young (in the egg or early larval stages) - at least this is one hypothesis to explain the remarkable increase in average year-class strengths of the latter since the 1960's when the pelagic fisheries became intense.

These interactions, however difficult they may be to determine quantitatively, must in principle be taken into account if management is to make the "best" use (however "best" is determined) of the resources as a whole. Apparent optimization of one element of the system, i.e., of the fishery on one species, is likely to lend to a less than optimal

situation as a whole. For example, if the objective is the greatest production of food from the sea, it does not make sense to maximize the catch of cod from the North Sea if by accepting a reduction of say 5 000 tons the catch of herring could be increased by 20 000 tons.

The influence of factors other than the direct effect of fishing are becoming more widely recognized. They mainly cause practical difficulties in analysis and interpretation, rather than in the definitions. For example, failures in recruitment brought about directly by fishing down the adult stock calls for drastic action as soon as the situation is recognized. However, in many stocks there are very large year-to-year natural variations in recruitment quite independent of any changes in adult stock so that it is not always easy to tell when the adult stock has been so reduced that recruitment is being affected. It may only be after a series of years of bad recruitment (and not always then) that arguments about the influence of heavy fishing on recruitment are settled. By that time it may be a long and painful business to rebuild the stocks. As another example, some stocks undergo, even in the absence of human intervention, long-term fluctuations due to climatic fluctuations. They may, therefore, at the commencement of exploitation, not be in equilibrium, and the observations of the characteristics of the stock at that time may perhaps not be usable as a guide to the subsequent impact of fishing.

These difficulties do not, however, in themselves add to the theoretical problems of determining in principle the objectives of management, at least in their simpler forms. If the objective is to maximize the catch over a period there will be some strategy that by maintaining the stock at a level that ensures, on the average, a good recruitment, while taking a substantial yield from most year-classes, will give the maximum average annual catch. However, the benefits to the individual fisherman or to the community as a whole of say an average catch of 10 000 tons is very different if this average is achieved by catching 10 000 tons every year, 20 000 tons every other year or 91 000 tons every tenth year, plus 1 000 tons in the other years. Either of the latter situations may well be less attractive than say a steady annual catch of 8 000 tons. That is the existence of year-to-year fluctuations, whose extent may change, possibly in response to different management policies, adds another dimension to the choice of objectives. Another form of this is the risk of disaster, or vulnerability to poor natural conditions; a policy may give high returns under normal conditions, but (possibly because the stock is reduced to a fairly low level), may result in a collapse when bad conditions occur. It is becoming recognized that many stocks have a much greater natural variability than is normally considered by the traditional biological or economic models, and that the best strategy under steady equilibrium conditions may not be the best under varying conditions. A preferable policy might be to take less under average conditions, so as to be able still to have some fishery even when conditions are poor. That is, large variations may in some cases require the objective to be modified from maximizing the total yield that, as an annual average, can be sustained over a long period, to maximizing (or at least maintaining at a high level) the catch that can be sustained in every year, even at the cost of smaller catches in very good years, or as an average over a year. This modification to objectives should be distinguished from the modification of models that becomes necessary when a simple steady-state model fails to predict accurately the reaction of a heavily fished stock to poor natural conditions. In this case the objective of MSY is not in itself invalidated provided proper emphasis is put on the "Sustainable" part.

The impact of human activities other than fisheries, on fish stocks, is increasing. On the whole, while they may change substantially the degree of success or other use of fisheries, they are not likely to influence the objectives of fisheries, or the strategy that would best achieve those strategies. For instance, there will always be a certain mesh size that will maximize the sustained catch in an inshore trawl fishery, and the value of that mesh size will probably not change much even if the stock were reduced by pollution.

3. MEASURES OF INPUT AND OUTPUT

The simple approach represented as its most typical example by the Maximum Sustainable Yield considered only one output - the magnitude of the catch - and gave little consideration to input at all. Economists and others have long criticized this, and emphasized the importance of the costs of the input. In particular they have considered that the economic return - the difference between the value of the catch and the costs of catching it - is one of the best measures of the success of a fishery (see, for example, Gordon 1954, and Scott 1955, and also earlier biological papers, e.g., Graham 1939, 1952). This approach has stimulated the use of the Maximum Economic Yield - defined as the maximum difference between the value of the catch and costs of catching it - as the best definable objective of management. It is clearly a more sensible objective than MSY, particularly for the numerous stocks which have a flat-topped yield curve. There is little value in adding half a dozen extra boats in order to add a few kilos to the total catch (especially as this will mean reductions in the catch of each individual boat).

MEY is a great advance on MSY, particularly in recognizing that management is concerned almost as much with reducing inputs as with increasing outputs - indeed the form of the yield curves for important groups of fish, e.g., shrimp, is such that the greatest practical benefit for their management is likely to be from reducing costs. One objection to MEY as the single, defined objective of management is that it is not uniquely definable. Within a multi-national fishery its position (in terms of catch, net economic return or fishing effort or mortality) will vary from country to country. Too much should not be made of this objection because unless the national differences (especially in the balance between costs and values) are very marked (and if they are, the country or countries with the worst cost: value ratio will soon be driven out of business), the positions of the MEY according to different national criteria will be clumped close together, usually well away from the (uniquely determined) position of MSY. The disadvantage of the MEY concept is that few fisheries are valued solely in economic terms. Countries may consider their fisheries primarily as sources of food, employment, or earners of foreign exchange; equally they may be as anxious to reduce energy inputs, or foreign exchange needed for ships or equipment, as to minimize the total economic input. Other measures of the success or otherwise of fisheries and their management are less quantifiable. Management action may be taken so as to minimize conflicts between groups of fishermen, nationally or internationally, or to improve the living of certain groups or areas.

These objectives are not completely compatible. Obviously, with a limited total catch maximizing the income per fisherman can only be achieved if the total number of fishermen is limited, and may require a reduction in their number that is, at least in the short run, socially undesirable. Where several species of different values are fished in the same area, a choice may have to be made between a large weight of the lower valued species (e.g., Alaska pollock) or a higher value but reduced weight from the higher valued species (e.g., halibut). The preferred balance between different species is likely to change from time to time as the uses of each species, or the cost of harvesting one or other species change. For example, the choice between halibut and pollock only became a real problem recently when, after more than a century of intense halibut fishing in the North Pacific, large-scale fishing for pollock became technically and economically feasible.

The situation appears even more complicated when some of the less quantifiable, non-commercial criteria which are being considered by environmental groups and others are given weight in choosing management procedures. Some of these concepts, e.g., the need to leave open as many alternative options for the future as possible, or to allow for the uncertainty that is unavoidable in nearly any scientific analysis, can be incorporated into the commercial objectives outlined above without any major revision, especially if enough weight is given to long-term rather than short-term considerations. For example, a strategy will not maximize the sustained yield in the proper, long-term meaning of "sustained" if there is a strong probability that with that strategy sooner or later there will be some unexpected environmental or similar event that reduces the stock to a very low level.

There are other concepts, e.g., the wish to maintain some ecosystems entirely undisturbed, or to minimize or eliminate the killing of marine mammals - or at least the more attractive ones such as porpoises or baby seals - which introduce quite different types of objectives. These additional concepts and objectives have received particular attention in connection with marine mammals and were extensively discussed at the Scientific Consultation on Marine Mammals held in Bergen, Norway, in September 1976 (FAO, in preparation). For a number of species of marine mammals there are uses - referred to in Bergen as the low-consumptive uses - that require killing or removing few, if any, animals from the population. These uses include captive porpoises in oceanaria, tourism (watching gray whales in California, or right whales and other marine mammals in Argentina, etc.) and the production of films, books, etc. The output from such uses, which can to a large extent be measured in terms of gross or net economic returns, employment, etc. on the same scale as the output arising from the commercial catches, should be added to the output from the catch to give the total output arising from any management strategy. To the extent the output from the low-consumptive uses is affected by the nature or abundance of the population and hence the management strategy - books may sell better if whales are, or are believed to be, threatened with extinction, but more people may travel to see whales if they are abundant - the strategy that best achieves a given objective (net economic return, employment, etc.) may be changed by considering the low-consumptive uses. At present the question of low-consumptive uses is not of great immediate practical importance because no stock is subject to both large-scale hunting and important conflicting low-consumptive uses, but if there were such a stock the two types of uses could be considered together without much difficulty in terms of general economic objectives.

It was also pointed out at the Bergen meeting that there was a range of objectives other than the economic and commercial ones of providing food, employment, cash incomes, etc. These other, ecological or ethical objectives included maintaining ecosystem stability, avoiding cruel practices and providing minimum stress for marine mammals. Some of these are compatible with the other objectives, or indeed are essential to them. For example, it would be difficult to sustain a commercial fishery at a high and relatively constant level unless the ecosystem were stable. Others, e.g., avoiding any killing, are partly or wholly incompatible with most traditional objectives.

This paper is not the place to argue the merits or demerits of such objectives, which indeed cannot be attacked or defended on scientific grounds. For the present purposes it is merely important to note that such objectives exist and, where they command significant national support, must be taken into account in determining national resource management strategy. The choice between objectives - putting emphasis on the harvest and the social and economic benefits from the harvest, or eliminating all killing, or all killing that involves undue cruelty - must be a political decision.

4. LONG-TERM AND SHORT-TERM INTERESTS

The balance between long-term and short-term interests can be crucial in determining management strategies. The role of the discount rate has been discussed by Clark and others (see Clark, 1976 for a general review). If costs are low, narrow economic considerations combined with a high discount rate could in theory lead to the extermination of resources with low natural reproductive rates. High costs of catching the last few animals are likely to make extermination an exceptional case, and harvesting beyond the MSY level (i.e., with a higher effort and lower catch) but at a sustainable rate is the more general

case if discount rates are high and management decisions are made solely on economic criteria.[1] This may not necessarily be a bad thing. A bird in the hand is always worth more than one in the bush even if not always as much as two. If a high discount rate is a true measure of the degree to which a dollar available today can be put to productive use and result in several dollars in a few years' time, then indeed it may be wise to fish beyond the MSY level to get more fish today even at the cost of less fish from that particular resource in the future. (The total fish production in the future could be higher if, for example, the early profits were invested in aquaculture).

The general point is, however, entirely valid. All management involves a balance between present and future catches, and the typical management strategy sets controls that reduce the catches that might otherwise be taken this year, in order that catches next year or in some later year will be larger. The choice of a particular strategy depends not only on how much potential catch has to be sacrificed now and how much extra could thereby be gained in the future, but also on the relative values of a kilo of fish or a dollar today compared with a kilo of fish or a dollar (adjusted if necessary to take account of inflation) in a few years' time.

Some of the existing concepts and definitions ignore this point or make, implicitly or explicitly, unlikely assumptions. The Maximum Sustained Yield in its present form gives equal weight to catches at any time, which is equivalent to a zero discount. That is, it is not concerned with the fact that there may have to be sacrifices (possibly considerable in the case of a stock that is badly overfished) to achieve the state which will give the MSY. It is therefore surprising that sometimes the attacks on MSY as a concept have been linked with the claim that more emphasis should be given to long-term rather than short-term interests. However, the point that the two interests are not necessarily synonymous (and are often opposed) is a valid one. Any management decision should be based on a reasonable balance between the two. To the extent that short-term interests are likely to be well represented at any negotiation, e.g., by groups of fishermen, the management agency itself should be prepared to pay particular attention to matters of long-term concern, and to be a spokesman and champion of future generations.

Another aspect of differences between long-term and short-term interests, or between general and special interests, lies in the degree to which management action in respect of a particular stock at a particular time should be considered as part of a controlled experiment to promote better knowledge of the resource and its exploitation, and hence in the long run ensure better management. If resource knowledge were perfect, it would be possible to determine the particular action (e.g., the allowable catch) which would best serve the chosen objectives, e.g., maintain a given whale stock at the MSY level, or bring it to that level at the most rapid, or the most generally acceptable rate.

Resource knowledge never is perfect, and the estimate of "optimum" position (in terms of say stock abundance, according to the chosen set of objectives) may depart quite a lot from the true position. If management aims at, and succeeds in, holding the pattern of exploitation at what is believed (wrongly) to be the 'optimum' position not enough new information may come in to provide a significantly improved estimate. A better long-term performance might be obtained by deliberately allowing the pattern of fishing to depart, for a period, enough to one side or other of the estimated position of the optimum to generate information giving a significantly improved estimate of the real position of the optimum. A similar experimental strategy might be pursued where several stocks of similar characteristics (e.g., independent stocks of minke whales) could be the subject of a com-

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1/ The concern here is with situations where a sole owner of a resource might take an apparently logical decision to fish beyond the MSY level. In practice in many fisheries the unreasonable logic of open access drives the effort past the MSY level unless all participants can agree on regulations to control effort. This gives the same result, but for quite different reasons.

prehensive experimental management strategy, applying different policies to each stock. Given a reasonably careful choice of alternatives, any loss that might occur in respect of individual stocks (or fisheries on them) in the medium term should be made up by better long-term management of all the stocks.

5. THE POSSIBILITIES OF DEFINITION

A strict definition of the general aims of conservation and management, if it could be achieved, would clearly be of great value in setting detailed regulations. Most conventions such as those setting up regional fisheries commissions contain some preamble on the virtues of conservation, explaining the general purposes of the commission. Similar expressions are contained in various more general documents, e.g., on the Law of the Sea. Clearly, other things being equal, the more precise these statements on general purposes were, the easier it would be to determine at some time in the future whether or not some specific proposal was consistent with the purposes of the regional commission, or in accordance with some agreed Law of the Sea. The arguments in the previous section suggest, however, that the hope to define in this way the Holy Grail of fishery conservation is in vain, and that it is impossible to define a "best" fishery policy because what is "best" will vary from time to time. What is considered the "best" policy at any one moment will be determined by the current preferences between different measures of input and output, the uses that can be made of different products from a given ecosystem, the weights given to long-term and short-term interests, as well as the knowledge (which will always be incomplete in some way) of how the natural systems operate, and what will be the effect of alternative actions. These are bound to change, and the stricter the definition made at the present, the more likely it is that this definition will make it difficult to pursue some objective that later becomes apparent, or that the defined objectives are inconsistent with additional knowledge that might be gained about the natural ecosystems.

Nevertheless, some general statement of purpose is highly desirable in many documents and agreements. The term "Maximum Sustained Yield" (when not too carefully defined) used to serve the purpose, but clearly is now inadequate or misleading. Insofar as a specific term or phrase is needed, it is likely that 'optimum utilization' or 'optimum sustainable yield' is at least as suitable as any other. Unlike some other terms, e.g., 'full utilization', it implies some balance between different factors (e.g., inputs such as costs, manpower or energy, and outputs such as gross weight of catch, net economic returns, etc., as well as social or political considerations). The concepts have been discussed in detail by the American Fisheries Society (Roedel (ed.), 1975) and others. Particularly in the form 'optimum sustainable yield' - which stresses the aspect of continuity and long-term concern, it does provide a broad general guideline for management.

The conclusions of a series of workshops held in Airlie, U.S.A., in 1975 are somewhat similar. This sought to replace MSY, whose weaknesses were well recognized, by another clearly definable objective. In this the participants were unsuccessful, and instead drew up a set of principles:

"1. The ecosystem should be maintained in a desirable state such that

(a) consumptive and non-consumptive values can be maximized on a continuing basis;

(b) present and future options are ensured;

(c) risk of irreversible change of long-term adverse effects as a result of use is minimized.

2. Management decisions should include a safety factor to allow for the facts that knowledge is limited and institutions are imperfect.

3. Measures to conserve a wild living resource should be formulated and applied so as to avoid wasteful use of other resources.

4. Survey or monitoring, analysis and assessment should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review."

As principles, these should be helpful to policy-makers in shaping their approach to management problems, but give little guidance in specific situations (how many vessels should the Peruvian Government authorize to fish in the coming months, and how much anchovy should they be allowed to catch; or, how many fin whales should be caught in the Antarctic next year - if any - to achieve a fair balance between the need to rebuild the stock quickly, and the desire for a current harvest).

The most important conclusion from these discussions is that management requires a very broad approach. Some consideration needs to be given not just to the stock of fish being harvested by a particular group of fishermen, but on the one hand all the other elements in the ecosystem with which the stock interacts, and, on the other, all the social and economic conditions which determine the actions of the fishermen, and the possibility of modifying these for the purposes of better management. This need for some degree of consideration of wider issues should not be exaggerated to the degree that the inability to make quantitative estimates of the effect of catching one species of fish on certain other fish species (or indeed on species of zooplankton) might be used as an excuse either to inhibit any development or to impede the introduction of desirable management measures. In the past the cry "do not decide yet, the evidence is not really conclusive" has prevented timely conservation and management of resources threatened with over-exploitation. It would be a pity if, with the swing of the environmental pendulum, the same cry were used to prevent the careful and controlled harvesting of new resources.

6. FUNCTIONS OF SCIENTIFIC ADVICE

In principle the scientific advisory function is simple - to provide a review of the state of the fish stocks, and particularly the effect of exploitation on them, and to advise on the effects (both immediate and long-term) in respect of the chosen objective (or objectives) of different management measures. It is not (at least in principle) the responsibility of the scientist to recommend one or other measure. There are exceptions to this when the scientists have a direct interest, as scientists, in some objective; for example, in the mid-nineteen sixties when the blue whale was very severely depleted (and appeared to be even more severely depleted than it probably was in reality), the scientists strongly recommended a complete ban on catching blue whales because extinction was a real possibility if no such action was taken, and prevention of extinction was of major scientific interest. Generally scientists are not concerned, as scientists, whether or not the maximum physical or economic yield is obtained. In fact, as scientists, they may prefer to see a stock of fish being over-exploited because of the biological information on changes in the parameters (growth, reproductive success, etc.) that might be obtained.

In practice the scientific advance can effectively have the force of specific recommendations - for example, if it shows that disaster will strike the fishery unless some action is taken. Less drastically, the analysis of a single-species fishery may show that using some particular mesh size will give a greater long-term catch than any other mesh. Since there are little practical difficulties in using one mesh size rather than another, the practical effect of this scientific conclusion is much the same as a recommendation to use this mesh size.

So long as objectives and the models of biological events were both simple, so too were the roles of scientist and administrator, and the distinction between these roles which seems highly desirable in principle could clearly be maintained in practice. The scientist could provide the administrator with the value of the sustainable yield, as a

function of effort or fish stock abundance - matters were particularly simple if this were the parabolic curve typical of the Schaefer model, or a similar curve with a clear and easily located maximum - and the administrator could pick the position (e.g., that giving the maximum physical yield) that best accorded with his objectives.

The theoretical distinction between the scientific and administrative functions has also a practical value. In any real situation both functions are likely to be difficult. The difficulties of the two functions are likely to be multiplied together if the attempt is made to tackle them simultaneously. In that case the solution of difficult administrative questions - e.g., how to agree on the allocation of shares in a fishery, in which the total harvest in the coming year should be no more than 50 000 tons, between participants whose aggregate demands are 90 000 tons - is likely to be sought in some revision of the scientific conclusions, e.g., by revising upwards the estimate of the 50 000 tons allowable catch. Attempts to reassess the scientific evidence for the sake of administrative convenience are unlikely to be to the benefit of science or (except in the very short run) of administration.

It is much preferable to follow the procedure used by many fishery commissions, and proceed through two quite distinct phases - first the preparation of a purely scientific report, reviewing all the scientific evidence, and then discuss what administrative action should be taken in the light of that report. In the second phase there is no re-opening of any scientific arguments other than to seek, where necessary, clarification of points in the agreed scientific report - agreed in this sense not necessarily implying a single conclusion or a single figure for the allowable catch, but including the setting out of points of differences and their implications for different management actions.

The distinction between scientific and administrative discussion, however desirable, cannot often be maintained in practice. The situation regarding both the state of the resources and the objectives may be so complicated that the scientific advice cannot be expressed simply. Further, even if science as a discipline can be separated from economics or social factors, the individual scientist cannot be isolated from his social and political environment. Often the scientist is at least as familiar with many of the non-scientific aspects of management problems as the administrator or other person with immediate responsibility for taking management decisions. The scientists would be failing in their wider responsibilities if, in this situation, they confined their advice to the purely biological aspects.

The situation can be best illustrated by reference to a hypothetical example, which is similar to several occurring in practice. The full line in Figure 1 represents the yield per recruit of a certain stock, as a function of the amount of fishing (strictly fishing mortality coefficient, though if conditions are reasonable, this will be about proportional to fishery effort as measured, for instance, by number of fishing days by a standard vessel). If, as is likely, the growth pattern is known, and a reasonable value of natural mortality can be assumed, then this yield per recruit curve can be estimated quite well.

From it the fishing mortality F_{MYR} corresponding to the maximum yield per recruit can be estimated. This estimate will be precise if the yield per recruit curve has a clear maximum (as will be the case if the fish has a relatively low natural mortality, or has the capacity for considerable growth after recruitment, e.g., the North Sea plaice), but will be rather vaguely defined if the yield per recruit curve is flat near the maximum (as will happen if the fish does not grow much after recruitment, e.g., North Sea herring).

The factors determining recruitment are less clearly known, and in any given year environmental factors (e.g., abundance of planktonic food for young fish soon after hatching) may be more important than the abundance of spawners. Nevertheless, on the average we may suppose that there will be some relation between the abundance of spawners and the strength of the subsequent year-classes, which in turn may be expressed (again under average environmental conditions) as some equilibrium relation between fishing mortality

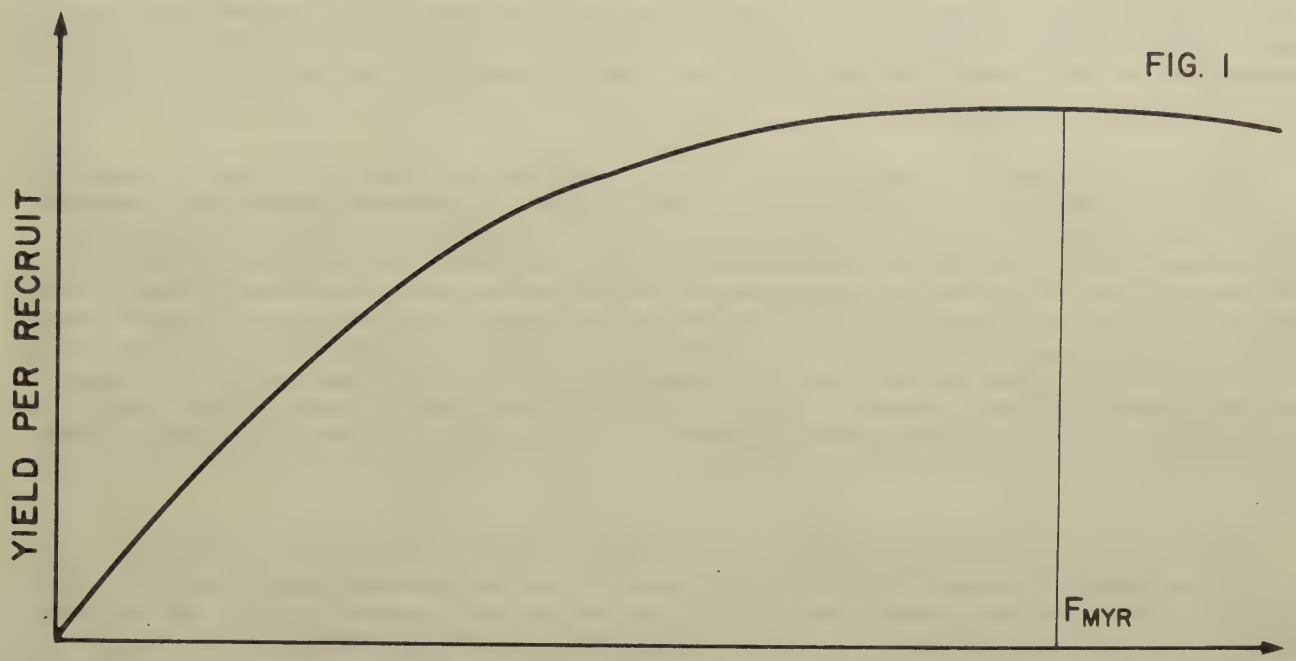


Figure 1. The yield per recruit, expressed as a function of the fishing mortality. The curve shown, with a shallow maximum, corresponds to a stock with a moderately high age at recruitment, or with natural mortality moderately high compared with the growth rate (in the sense of the rate at which the fish approaches its maximum size). Flatter curves would be obtained with higher ages at recruitment, or natural mortality. Lower values would produce a more pronounced maximum, at a lower value of fishing mortality.

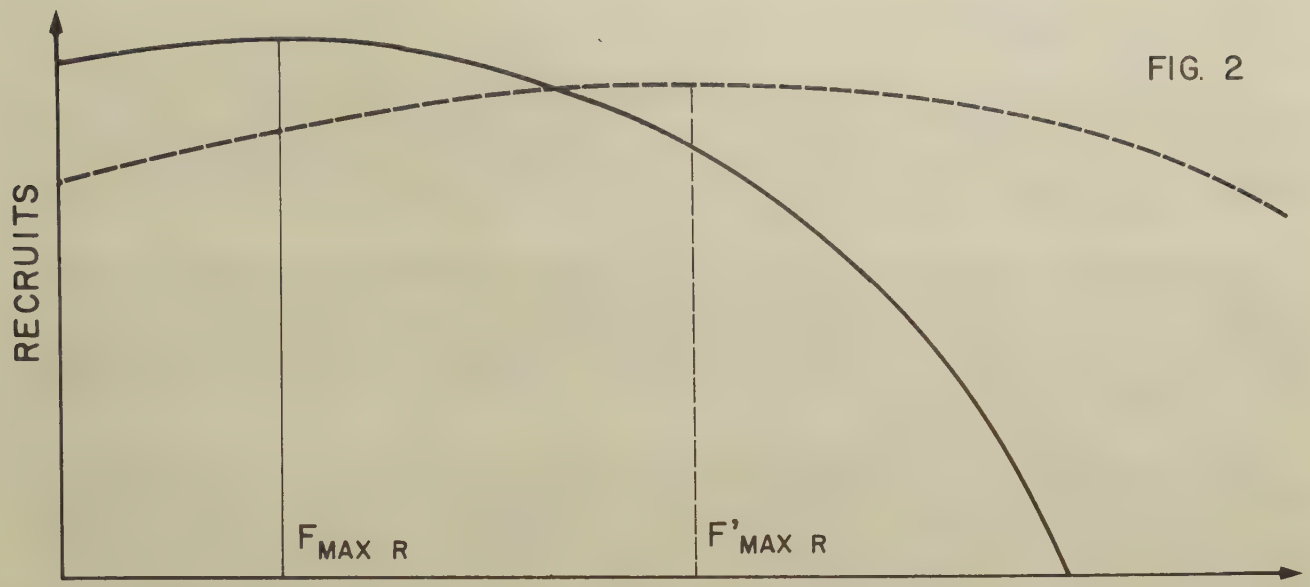
and recruitment (Figure 2). (For the present purposes we will ignore the possibly complicated interaction between environmental influences on recruitment and those of stock size, such that, for example, the stock size giving the maximum recruitment will be different under different environmental conditions, or that small stock sizes will only result in poor recruitment if environmental factors are also poor).

The recruitment/fishing mortality curve of Figure 2, if known, will define some mortality, $F_{MAX\ R}$ which gives the greatest recruitment. Further, the curves of Figures 1 and 2 can be combined to give the estimated relation between total yield and fishing mortality (Figure 3), which will in principle define some value $F_{MAX\ Y}$ giving the maximum yield. In practice the curves in Figures 2 and 3 will not be clearly defined, and the observed data will seldom be good enough to distinguish between the full curves, and alternatives such as the broken curves in Figures 2 and 3, which give quite different "optimum" positions $F'_{MAX\ R}$ and $F'_{MAX\ Y}$.

Scientific advice that attempted to spell out all the alternatives, first between the optimum fishing mortality according to different objectives (maximum gross yield, maximum net economic benefit, etc.), and second between different interpretations of the scientific evidence (according to the different sets of curves) would run the risk of being too difficult to follow. Also, by leaving questions of interpretation or of objectives to be resolved (if they are resolved at all) by the policy makers, the attention of these administrators may be diverted from their other important tasks, of deciding how to implement one or other of the alternative actions. For example, action in ICNAF has been facilitated when the scientists have proposed a single figure for the Total Allowable Catch from a particular stock, thus allowing the Commissioners to concentrate on the measures (particularly allocations to individual countries) required to keep the catches within the limit of the TAC.

This procedure, involving a de facto adjustment of responsibilities between scientist and administrator, goes smoothly if there is some objective method of calculating the TAC, using some pre-determined formula which takes account of the uncertainties in the scientific data, and the differences in possible objectives. One formulation which has been useful is the value of $F_{0.1}$. This is the value of fishing mortality at which the marginal yield-per-recruit (i.e., the increase in yield-per-recruit achieved by an increase of one unit of effort) is one-tenth of the marginal yield per recruit at very low levels of mortality.

The logical basis for this value is mixed, but reasonably clear. With such a small marginal yield-per-recruit the economic incentives for further increases in fishing are small (at least on a per-recruit basis). The total yield-per-recruit will, of course, be less than with F_{MYR}, but unless the yield per recruit curve has a long shallow left-hand shoulder the difference will not be large (only 1% of the maximum yield-per-recruit in the case of the classic parabolic curve). At the stock levels concerned it is almost certain that increased fishing (and hence smaller stocks) will, on the average, reduce recruitment if only to a small extent. Thus the advantages of $F_{0.1}$ over higher levels of fishing mortality on a per-recruit basis are even stronger in terms of actual yield. Thus $F_{0.1}$ is likely to be an upper limit to the desirable value of F (and hence of TAC). In the serious situations, where the current amount of fishing is much too high, the fact that the "optimum" value of F is probably below $F_{0.1}$ will not be much of a disadvantage. The value of $F_{0.1}$ provides a definite target to show how far the reduction must go at the least, and this can be most helpful. In any case the merits of $F_{0.1}$ are not so much those of the particular value itself (for example, $F_{0.15}$, where the marginal yield per recruit is 15% of the initial value might be preferable on some grounds), but that it enables the scientists to calculate in a clear and objective manner, a TAC (or similar expression) on which administrative negotiations and decisions can be based.



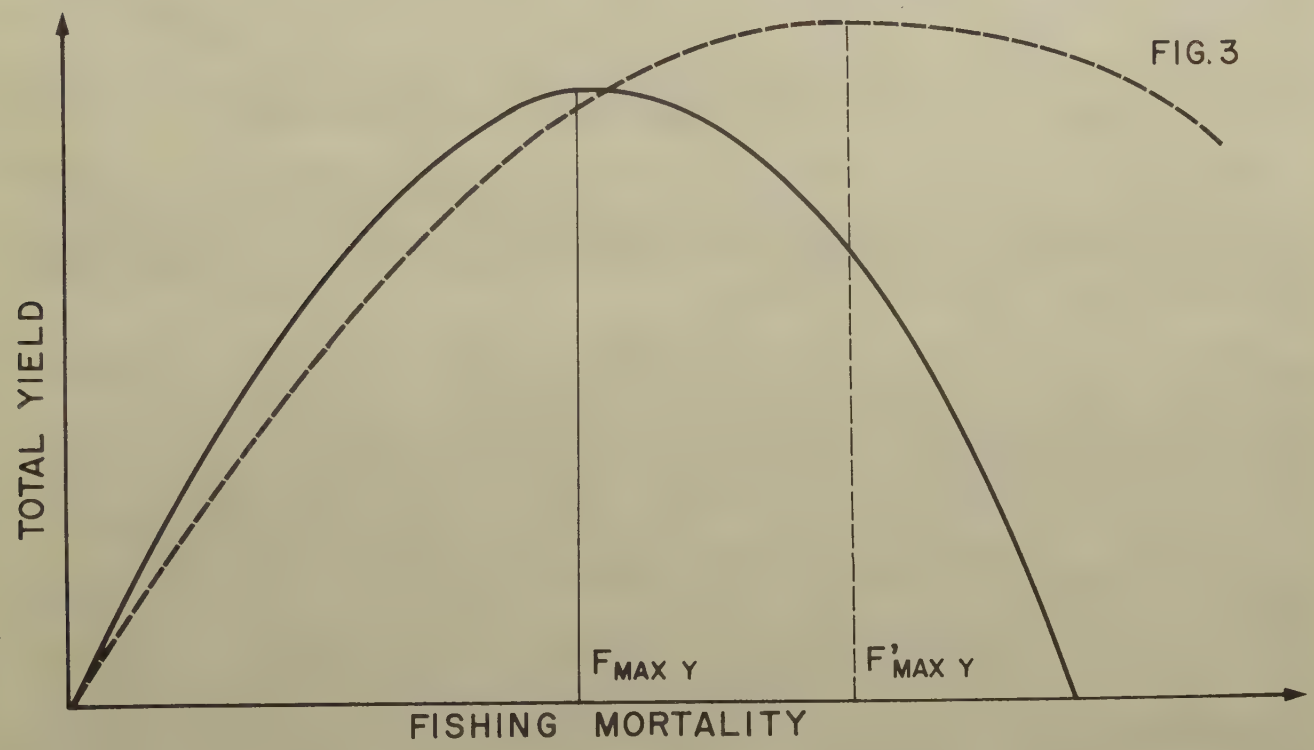


Figure 2 (above). The number of recruits, under the steady state conditions, as a function of fishing mortality. The broken line shows an alternative relation. The two may not be distinguishable in practice using observed data from a particular stock.

Figure 3 (below). The relations between total yield and fishing mortality corresponding to the relations in Figures 1 and 2 between fishing mortality, yield per recruit, and total yield.

7. MECHANICS OF ADVICE

The step between the pure scientific analysis of information, and the subsequent administrative decision, in which the policy-maker is provided with scientific advice, and uses this advice in making his decisions, is often the most critical in achieving good management. The nature of the advice, and the mechanisms through which it is prepared and presented needs careful consideration.

The essential qualities in scientific advice have been reviewed by the earlier ACMRR Working Party on the Scientific Advisory Function (FAO, 1974). This report stressed the importance of timeliness; accuracy and precision; clarity; scope and relevance; and acceptability; and noted how through failures in the scientific advice in one or other of these qualities, many important fisheries had not been managed properly, often with serious economic and social consequences.

The discussions in the preceding sections are directly concerned with the scope and relevance of the advice, i.e., the degree to which it takes account of all the interacting interests that together determine the objective of management. Given that the scientists concerned are aware of the chosen objectives of national policy, the advice should have adequate scope, and be fully relevant, e.g., if the national policy demands increased food of all kinds, the advice in respect of a given fish stock will not merely identify the position of MSY, but take note of the extent to which exploitation at MSY or to one or other side of it could facilitate increased catches of other species, or require less inputs, thus freeing resources for increasing the production of other types of food.

Many aspects of timeliness, accuracy and precision, and clarity are fully set out in the previous Working Party report, and need not be repeated here, though it is probably worth stressing again the importance of these factors. That report does not, however, do more than touch in passing on the problems of producing advice, e.g., on catch quotas, with an acceptable degree of accuracy and precision.

This is, of course, a problem of scientific research; precise and accurate advice must be based on a precise and accurate understanding of events in the resource, which requires good research. One essential element of this research is basic information (catch and effort statistics and related biological data) from the commercial fisheries - and the collection, compilation and dissemination of these data is usually the largest and most important international activity in respect of stocks exploited by more than one country - but good advice needs much more. There are several general problems that have not been solved. The dynamics of single species stocks in uniform environments are believed to be reasonably well understood, so that the scientific work in advising on them is mainly the relatively simple matter of measuring a few parameters and applying well-established models. However, even in these fisheries the nature of the relation between stock and recruitment is likely to be important but not well understood (see, for example, Ricker, 1954; Cushing, 1971, 1977). The study of stock and recruitment is therefore one major research area needing attention. Others are the general question of multi-species fisheries, and fisheries on different, interacting species. These problems have often been discussed (e.g., at the Eighth Session of ACMRR), but scientists are still a long way from being able to predict with any confidence what the effect of heavy fishing of one species will be on some other species, or how fairly generalized fishing on a mix of species will affect the balance between species. A final scientific question (or range of questions) that will need some intensive research to deal with is that of instability and non-equilibrium conditions. Most theoretical biological and economic models (but see Clark, 1976) as currently applied to fisheries, are based on the consideration of fairly simple conditions, usually where most elements in the system are in a steady state, other than perhaps some change in the amount of fishing. In fact both human and natural elements are likely to be in a permanent state of flux, and the rate of change of the pattern of fishing seems to be increasing - few, if any, modern fisheries have experienced the period of nearly two

decades of relatively constant effort that occurred in the North Sea trawl fisheries from 1920 to 1938, on which Beverton and Holt's (1957) classic work was based. The optimum strategies based on steady state analyses may well not be the best under variable conditions. For example, it has been shown that the yield from a complex of stocks with high variable recruitment is greater if the fishing fleets move in the correct manner between stocks than if each is exploited at the best constant rate (Garrod, 1973; Pope, 1973). These three topics alone (stock/recruitment, multi-species, and variability) will require major research efforts if scientists are to be able to advise adequately.

Another aspect of the provision of advice that has been examined in some detail by previous groups is that of providing enough support to the scientists to enable them to perform adequately. Though the detailed arguments need not be repeated here, it is worth stressing that the losses that may occur in the absence of good scientific advice can very greatly exceed the costs of providing that advice. These costs cover such matters as collection of basic data, analysis by national scientists (including carrying out original basic research) and, where needed, arrangements for bringing together individual national studies in respect of resources exploited by more than one country. All these are essential elements of any management programme, irrespective of the detailed aims or objectives chosen for the particular resource concerned.

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M-43
ISBN 92-5-100281-9